Day 1 of 4

Science of Nuclear Radiation

Lecture 1

Nuclear weapons are the most powerful of all Weapons of Mass Destruction. The detonation of a nuclear device would result in catastrophic physical (and other) effects including:

- blast effects (shock wave)
- thermal effects
- radiation contamination
- tremendous psychological impacts worldwide.

During the 'Cold War' between the United States and the Soviet Union (late1940s to 1989), the nations of the world lived with the constant threat of nuclear war. Since the end of the Cold War international terrorist organizations have made efforts to gain access to WMDs, including nuclear weapons, by attempting to recruit nuclear weapon scientists. In addition, certain nuclear nations may still pose a military threat to others. These countries include:

- India
- Pakistan
- Peoples' Republic of China
- North Korea
- Iran
- Israel

Nuclear weapons are designed and constructed based on two unstable materials, uranium-235 and plutonium-239. Such weapons are not manufactured directly from uranium; the naturally-occurring mineral must be processed before it is usable in a weapon. Enrichment processes are costly and extremely complex. Plutonium does not exist in nature and is only produced within a nuclear reactor. Because of these limitations, a terrorist organization can acquire a nuclear weapon only by:

- obtaining an intact nuclear weapon from a national stockpile; or
- obtaining fissile material and then using it in a nuclear explosive

Properties of the Atom

The tremendous power of nuclear weapons originates from reactions occurring within atomic nuclei. In nuclear reactions matter is converted to energy (recall the famous equation $E = mc^2$).

The amount of energy generated is many orders of magnitude greater than that available from any chemical reaction.

Elements and atomic structure

A total of 92 elements occur naturally. Hydrogen (H) is the lightest (having 1 proton).

Uranium (U) the heaviest, with 92 protons. There are also at least 25 artificially-created elements, termed transuranics (i.e., 'beyond uranium') elements. An atom is composed of a central nucleus containing most of its mass, with electrons orbiting around the nucleus. The nucleus consists of protons and neutrons. The proton is a particle possessing a positive electrical charge. The neutron is an uncharged particle with a mass similar to that of the proton. Electrons are negatively charged particles of extremely low mass which orbit the nucleus.

Isotopes

Atoms of different elements have different numbers of protons in their nuclei. The term **atomic number** describes the number of protons in a nucleus. Elements may contain varying numbers of neutrons in the nucleus. The total number of protons and neutrons in an atomic nucleus is termed the atomic mass. Atoms may have the same number of protons but different numbers of neutrons. They are still the same element, but are termed **isotopes**. Some isotopes are known to be quite unstable. This instability = **radioactivity**.

Two Isotopes of Uranium

	Abundance	Protons	Neutrons	Electrons
Uranium-238	99.3%	92	146	92
Uranium-235	0.7%	92	143	92

Questions

1. What is the composition of $^{238}{}_{92}U$?

   a. 238 protons, 146 electrons, and 92 neutrons. It is a nucleon of uranium.

   b. 92 protons, 92 electrons, and 146 neutrons. It is an isotope of uranium.

2. What is the atomic composition of $^{137}55Cs$?

   a. 55 protons, 55 electrons, 82 neutrons. It is an isotope of cesium.

   b. 137 protons, 137 electrons, 82 neutrons. It is an isotope of uranium.

In order to identify the individual isotopes of a given element, the following notation is used:

A X Z

Where:

X = chemical symbol of the element

Z = atomic number (number of protons)

A = atomic mass number (protons + neutrons)

235 U 92

Isotopes are often represented by mass number and chemical symbol only, for example ^{235}U.

Radioactivity

The nuclei of certain naturally-occurring isotopes, and of others produced artificially, contain excess energy, i.e., they are unstable. To attain stability, those energetic nuclei emit that energy in the form of nuclear radiation. Isotopes which emit ionizing radiation from their nuclei to achieve stability are termed **radioactive.** Radioactive isotopes are referred to as **radioisotopes** or **radionuclides**. The half-life of a radioisotope is the time required for half the atoms of a sample to decay to non-radioactive forms. Half-life values range from fractions of a second to years, depending on the isotope.

Questions

3. Radiological emergency response personnel are called upon to deal with accidents that involve radioactive nuclides or “radionuclides.” The nuclei of these atoms contain excessive energy that makes them:

   a. more stable and unlikely to transform into another nuclide.

   b. more unstable and likely to eject alpha or beta particles and energy.

4. When unstable nuclei eject neutrons or protons and release energy, the process is known as

   a. radioactive decay.

   b. ionization.

Ionization: When Radiation Interacts with Matter

Ionizing radiation greatly increases the risk of certain forms of cancer in humans. Ionizing radiation results in the deposition of energy in living tissue. Radioactive particles or waves (alpha, beta, gamma radiation and neutrons) all contain significant energy. Transfer of energy to other atoms may occur by ionization. Ionization is a process which results in the loss of an electron from an atom or molecule, thereby leaving it with a net positive charge. Ionization will occur if incoming radiation transfers sufficient energy to dislodge one or more electrons from the outer orbitals of the recipient atom. The ionization process is especially significant in DNA. When an organism’s tissue is bombarded with radioactive particles or waves, the incidence of DNA mutation is greatly increased. DNA chains will have a significantly greater chance of fragmenting and re-combining, resulting in the coding for new, undesirable and possibly detrimental changes in the affected organism (for example, development of carcinomas (cancer).

Questions

5. Ionization is an important concept for the radiological emergency responder to understand because:

   a. it is the basis for the biological effect caused by radiation and it provides the evidence that radiation is present.

   b. it describes how protons are removed from the nucleus of an atom, causing biological damage to a cell.

6. An **ion** is any atom that has lost:

   a. a proton.

   b. an electron.

Types of Ionizing Radiation

There are four types of ionizing radiation which can be emitted from radioactive elements. All are potentially hazardous and include:

- Alpha particles
- Beta particles
- Gamma rays
- Neutron particles

Alpha Radiation

When large, unstable nuclides such as uranium decay, they may emit several forms of radiation.

One common form is a particle composed of two protons and two neutrons. This form is termed *alpha* radiation.

Alpha radiation is relatively heavy, of relatively low energy, and carries a net positive charge.

Alpha travels only a few cm in air and has little penetrating power.

Most alpha radiation is stopped by one to two inches of air, or a sheet of paper or cloth.

Alpha cannot penetrate the outer layer of dead skin on the body. Sources of alpha radiation:

- Uranium (nuclear power plants and nuclear weapons)
- Plutonium (nuclear weapons)
- Americium (smoke detectors)
- Thorium (tungsten welding rods, coatings on large lenses of telescopes)

Beta Radiation

Essentially an electron minus an electrical charge, ejected from the nucleus at high energy. Given its extremely small size, beta particles have extremely low mass. At high exposures beta-emitting radionuclides can cause injury to the skin and surface body tissues. Ionization occurs due to the beta particle scattering electrons from target atoms. Beta radiation has a limited penetrating ability; range in air about ten feet. It should be shielded by ¼ inch of plastic sheeting, aluminum foil, thick clothing, or safety glasses. Beta radiation becomes an internal hazard if the beta emitter is ingested or inhaled in such cases the source of the beta radiation is in proximity to body tissues and can deposit energy over a small area.

Beta particles are emitted from:

- used nuclear reactor fuel and nuclear weapons fallout (for example, as strontium-90)
- some industrial radioactive sources such as cesium
- tritium in glow-in-the-dark EXIT signs, watch dials, and night-sights on firearms
- radioactive nickel in chemical agent detectors

Gamma Radiation/X-Rays

Gamma rays and x-radiation have no mass and no charge. They are composed of electromagnetic energy, not matter. Gamma radiation can be extremely destructive to living tissue via ionization.

A single gamma ray may ionize many thousands of atoms along its travel paths. Because gamma and X-ray radiation have no charge and no mass, they have very high penetrating power. Gamma rays travel great distances in air (up to miles) at the speed of light. Gamma radiation and X-rays must be shielded by very dense materials such as:

- concrete
- lead
- soil (one foot or more)
- steel (several inches)

Sources of gamma radiation:

- uranium
- plutonium
- radioactive cobalt and cesium
- industrial radiation sources
- medical sources
- cancer treatment machines

Neutron Radiation

A neutron, which occurs within an atom's nucleus, has significant mass but no electrical charge. Ionization of matter occurs from collision between a neutron and a target atom. Neutron radiation has a very high penetrating ability – they are difficult to shield. The range for neutrons in air is very far (miles). Neutron radiation is therefore a whole body hazard (internal and external). It easily penetrates body tissues and is quite destructive to tissue. Neutron radiation is best shielded by materials with a high hydrogen content such as:

- concrete (a foot or more)
- water (several feet)
- soil (several feet)

Sources of neutrons:

- nuclear fuels within a nuclear reactor
- burst of radiation from an exploding nuclear weapon
- plutonium
- californium
- americium

Questions

7. If you identified the radionuclides involved in a transportation accident and found that they emit alpha, beta, and gamma radiation, you would conclude that

   a. the radiation presents an internal hazard only.

   b. the radiation presents an external as well as an internal hazard.

8. Your radiation detection instrument indicates the presence of gamma radiation. Gamma radiation ____________by protective clothing.

   a. can be stopped

   b. cannot be stopped

9. If a material has a half-life of 1 minute, how long will it take for 100 curies of that material to decay to 25 curies?

   a. one minute.

   b. two minutes.

10. An accident involving a radiopharmaceutical shipment includes chromium-51 (^{51}Cr), which has a half-life of about 27 days. If 800 curies of the ^{51}Cr spilled and were not diminished by any natural effects, at the end of 27 days due to radioactive decay processes.

    a. there would be no ^{51}Cr left

    b. only 400 curies of ^{51}Cr would remain

Day 2 of 4

Nuclear Weapons

Lecture 2

Nuclear Fission

The **fission** process relies on the inherent instability of radionuclides. The nuclei of some heavy isotopes, in particular uranium-235 (^{235}U) and plutonium-239 (^{239}Pu), can split when they are bombarded by outside neutrons. This splitting is termed **fission**. A neutron smashes into the nucleus of a fissionable atom, resulting in splitting of the unstable nucleus. This results in the production of two or more fission products, more free neutrons and a tremendous amount of energy in the form of heat and light. When nuclear materials are tightly packed, such a process will cascade, resulting in an avalanche of neutrons being released which go on to split more and more nuclei. Each generation of neutrons released can generate a tremendous number of fissions. This phenomenon is the so-called **nuclear chain reaction**.

In commercial nuclear reactors, the fission chain reaction takes place slowly and in a controlled manner. In nuclear explosions, the chain reaction occurs at an extremely rapid and uncontrolled pace. Large quantities of U-238 exist in nature, but U-238 does not readily undergo fission. For this reason, U-238 cannot be used in a nuclear explosion.

Some isotopes such as uranium-235 (235U) or plutonium-239 (239Pu) undergo fission relatively easily and are termed fissile. Because of this capability, fissile isotopes are used to generate energy in nuclear reactors. The fissile capability is also important to cause a nuclear explosion. Fissile isotopes are extremely rare in nature.

Natural uranium consists of:

- 99 percent U-238
- < 0.7 percent U-235.

Plutonium-239 does not occur naturally.

Highly complex industrial processes needed to increase the concentrations of U-235 and to generate Pu-239. To maximize the weapon's explosive effect requires that a variety of important requirements be fulfilled.

Question

1. Naturally-occurring uranium is mostly ___, whereas the fissile component most useful for nuclear weapons is the ___ form.

   a. U-235, U-238

   b. U-233, U-235

   c. U-238, U-235

Critical Mass

Sufficient nuclear fuel must be present and in the proper configuration. So successive generations of neutrons can cause greater numbers of fission reactions. The quantity of fuel capable of sustaining a chain reaction is termed a critical mass. To cause a nuclear detonation, a weapon must be equipped with an amount of uranium or plutonium that exceeds the mass necessary to support a chain reaction, i.e., a **supercritical mass** of fissionable material.

When constructing a nuclear weapon it is essential to keep fuel materials below critical mass; otherwise, a critical or supercritical mass may melt or possibly explode. Prior to detonation, therefore, the fuel must be separated into several pieces of fissionable material, all below critical mass. At the time of detonation, the mass is made supercritical by changing its shape or configuration.

Nuclear Fusion

Under extreme heat and pressure the nuclei of two isotopes of hydrogen (deuterium and tritium) can fuse together to form a single atom of helium. This process is **nuclear fusion**. Nuclear fusion occurs in the sun and is responsible for producing light, heat and other energy forms released by the sun. The two conditions required for fusion are:

(1) extremely high temperatures (to accelerate the nuclei); and
(2) high pressure density (to increase the probability of interaction).

For the development of a weapon, the only practical way to obtain the required temperatures and pressures is by means of a nuclear fission explosion. Therefore fusion weapons must contain a fission component.

Types of Nuclear Weapons

Nuclear weapons are explosive devices that rapidly release the energy generated from the fission or fusion of atomic nuclei. Nuclear explosives are thousands of times more powerful than any known chemical explosive. The explosive power, or yield, of nuclear weapons is typically expressed in terms of the quantity of TNT that would release an equivalent amount of energy, often measured in thousands of tons of TNT (kilotons, kT). For the most powerful weapons, however, yield is measured in millions of tons of TNT (megatons, mT). The first of the fission bombs (July and August 1945) had yields in the range of 10 to 20 kt. Considerably larger yields, however, have since been designed for fission weapons.

Basic types of nuclear weapons: **fission**, **boosted fission**, **thermonuclear**.

Fission weapons are designed to rapidly assemble a supercritical mass of fissile material to create an uncontrolled fission chain reaction. Fission weapons are the only type of nuclear weapon ever used in wartime. The U.S. military used one fission weapon against the Japanese city of Hiroshima and a second against the city of Nagasaki at the end of World War II, in August 1945. There is concern that terrorist organizations could build fission weapons if they could acquire sufficient fissile material (either plutonium or **highly enriched uranium, HEU**). Terrorists could also obtain fission weapons from nations storing them in their nuclear arsenals. The most difficult challenge for a terrorist organization attempting to construct an improvised nuclear device is obtaining the fissile material.

Explosive Yields of Nuclear Weapons

When we discuss the yield of a nuclear weapon, we typically talk in terms of kilotons or megatons TNT equivalent. The "yield" of a nuclear weapon is a measure of the amount of explosive energy it can produce. The yield is given in terms of the quantity of TNT that would generate the same amount of energy when it explodes. Thus, a 1 kiloton nuclear weapon is one which produces the same amount of energy in an explosion as does 1 kiloton (1,000 tons) of TNT. Similarly, a 1 megaton weapon would have the energy equivalent of 1 million tons of TNT.

Question

2. A 25-kiloton nuclear weapon produces the same amount of energy in an explosion as does ____ tons of TNT.

   a. 25 million

   b. 25 thousand

   c. 2.5 thousand

Nuclear Weapon Types

At the time of detonation, the nuclear fuel is made supercritical by changing its shape or configuration.

Gun-type

The simplest type of nuclear weapon. Two pieces of fissionable material, each below critical mass, are brought together rapidly to form a single, supercritical one. The gun-type assembly occurs in a tube in which a high explosive is used to blast one subcritical piece of fissionable material from one end of the tube into a second subcritical piece held at the opposite end. When the two masses collide, they form a **supercritical mass** which results in a nuclear detonation. The "Little Boy" bomb dropped on Hiroshima during World War II was a gun-type fission weapon containing 64 kg of 80% enriched uranium with an explosive yield of 14 kilotons. The uranium-235 atom can split in many different ways with numerous products. The equation shows one possible fission reaction:

$$^{235}U + \eta \rightarrow {}^{95}Sr + {}^{139}Xe + \_\_\_\_ + 180\ MeV$$

Implosion Weapons

A sub-critical mass of ^{235}U or ^{239}Pu is compressed to produce a supercritical mass. Compression achieved by detonation of specially-positioned high explosives around a sub-critical sphere of fissionable material. The imploding blast wave from the explosives compresses the sphere of fissionable material, thus making the mass supercritical. Once compressed the mass will undergo a rapid chain reaction. The first nuclear weapon ever exploded, at the "Trinity" test near Alamogordo, New Mexico on July 16, 1945, was an implosion-type weapon. The "Fat Man" bomb used against Nagasaki in World War II was an implosion-type weapon, with an explosive yield of about 21 kT. Implosion-type weapons are much more difficult to design and construct than gun-type weapons; the explosive components and fusing systems are much more complex. Thermonuclear Weapons. Thermonuclear weapons derive their explosive yield from the combined power of nuclear fission and fusion. An initial fission reaction with a plutonium fuel generates the extreme temperatures needed to trigger a secondary fusion reaction. The fission component of a thermonuclear weapon relies upon implosion of the plutonium fuel. Radiation from the fission explosion heats and compresses a separate core of deuterium and tritium, which undergoes fusion. Thermonuclear weapons are significantly more difficult to design, build, and maintain than fission weapons. Thermonuclear weapons can be extremely powerful, with yields measured in megatons (mT). The largest nuclear weapon ever produced was the Tsar Bomba tested by the USSR on October 31, 1961. The USSR claimed that the designed yield of the Tsar Bomba was 100 megatons, but the yield was reduced to 50 megatons for safety reasons.

Improvised Nuclear Devices (INDs)

These devices may be fabricated in a completely improvised manner or may be a modification to a weapon already present in a national nuclear stockpile. The ability to obtain fissile material is a concern, given the fall of the Soviet Union and subsequent black market operations. The possibility exists that an IND could possess a substantial yield, as we would expect for a tactical or strategic nuclear weapon; however, the more realistic scenario would be a low-yield device of 5 kT or less that could be easily concealed and transported. Radiation released from the blast may injure large numbers of people. The spread of radioactive fallout will create panic among the general public. It is possible that substantial radiation exposure may affect first responders working at ground zero.

Day 3 of 4

Effects of Nuclear Detonations

Lecture

The energy released by nuclear explosions result in extensive damage to buildings, infrastructure, and humans and other biota. Nuclear detonations can potentially release millions of times more force than the largest conventional explosions (e.g., TNT). Both nuclear and conventional weapons rely on the destructive force of the blast or shock wave. However, the temperature reached in a nuclear explosion are markedly higher than that in a conventional explosion, and a large proportion of the energy is released in the form of heat and light. Nuclear explosions are also accompanied by:

- radiation
- fallout
- electromagnetic

Blast, thermal radiation, and prompt ionizing radiation occur within seconds of the detonation. Delayed effects, including radioactive fallout, inflict damage over minutes to years. The relative distribution of these effects depends on:

- yield of the weapon
- location of the detonation (i.e, in the air, at ground level)
- characteristics of the environment of the blast (open area or surrounded by structures)

Yield

For a low altitude atmospheric detonation of a 20 kiloton weapon, energy is distributed as:

- 50% as blast (overpressure and high winds);
- 35 % as thermal radiation, composed of a wide range of the electromagnetic spectrum, including
    - Infrared
    - Visible
    - ultraviolet light
    - soft x-rays;
- 15 % as nuclear radiation, including
    - 5% as initial ionizing radiation composed of neutrons and gamma rays emitted within the first minute after detonation
    - 10% as residual nuclear radiation (fallout)

Blast

The major proportion of energy from a nuclear weapon is as blast and shock waves.

The pressure from a nuclear blast can create winds of hundreds of miles per hour. At the instant of a nuclear explosion, the heat from the fireball produces a high-pressure wave which develops and moves outward producing the blast effect. The front of the blast wave (**the shock front, shock wave, or incident shock wave**) is a moving wall of highly compressed air which travels rapidly away from the fireball. The shock wave of air radiates outward, sharply increasing air pressure. When this shock wave comes into contact with a solid object, it will either move the object in the direction of the wave propagation or shatter it, depending upon the strength of the shock wave and the characteristics of the object. The air immediately behind the shock front is accelerated to high velocities and creates a powerful wind. These winds in turn create pressure against objects facing the blast that will knock the objects down. The **overpressure** reaches its maximum value upon the arrival of the shock wave. **Overpressure** refers to the increase in atmospheric pressure as a result of the detonation. Blast effects are usually measured by the amount of overpressure, that is, the pressure in excess of the normal atmospheric value, in pounds per square inch (psi). Urban areas are completely destroyed by overpressures of 5 psi, with heavy damage extending out to at least the 3 psi contour. Overpressures of 2 psi will seriously damage frame and composite houses. No structure can withstand 10-12 psi overpressure.

Blast Effects on Humans

Upon contact with humans, the nuclear shock wave will push the person in the direction of propagation and compress the body as the wave passes, resulting in damage ranging from burst eardrums to destruction and liquefaction of the internal organs, depending upon the amount of overpressure. At overpressures of 1 psi, people can be knocked down; at 2-5 psi eardrums are ruptured. Pressures of over 40 psi are sufficient to cause lethal effects. Organs most susceptible to overpressure damage: eardrums, lungs, digestive tract. A greater danger from overpressure comes from the collapse of buildings. Many objects will become airborne. Serious injury or death can also occur from impact after being thrown through the air. The blast also magnifies thermal radiation burn injuries by tearing away skin.

Thermal Effects

35 % of the energy of a nuclear weapon is released as heat, reaching temperatures at the moment of detonation of 180,000,000^{o}F (100 million degrees C). Such temperatures are so extreme that about one-third of the energy is converted into electromagnetic radiation (specifically x-rays). This electromagnetic radiation, consisting mostly of x-rays, is absorbed by the local atmosphere around ground zero, heating it to extremely high temperatures and forming an extremely hot sphere of air and gaseous weapon residues, the so-called **fireball.** The surface temperature of the fireball is about 14,400^{o}F (8000^{o}C). At these temperatures, the non-fissioned components of the weapon are vaporized. This heat incinerates all matter within a large distance.

Prompt Radiation

Approximately 15 percent of the energy released from a nuclear detonation occurs as various types of radiation. The **initial nuclear radiation** comprises about one-third of this total. Initial nuclear radiation, also termed prompt radiation, is defined as that produced within about one minute from detonation. Prompt radiation is quite destructive. They are composed mainly of neutrons, gamma rays, x-rays, and alpha and beta particles. Prompt radiation is lethal to all life within a few thousand yards. At these distances blast and thermal effects are also lethal. The electromagnetic radiation (chiefly gamma rays) interacts with the molecules in the air (and debris) so that its intensity is eventually reduced**.**

Health Effects of Radiation

Radiation damage affects the structure and function of cells. The effects on cell structures lead to a wide variety of changes within the cell, which can result in death of the cell or the entire organ, and changes in the genetic makeup of an individual that can lead to delayed effects. Radiation effects are generally classified as early (or acute) and late (or chronic). The terms **early** and **late** refer to the length of the latency period after the exposure. The **latency period** is the time interval between dose and detection of symptom. Early (acute) radiation health effects are those clinically observable effects on health that are manifested within two or three months after exposure. Their severity depends on the amount of radiation dose received. Examples of acute radiation effects include skin damage, loss of appetite, nausea, fatigue, and diarrhea. Late effects can occur years after exposure; examples are cancer, leukemia, cataracts, and genetic effects. Radiation damage can be repaired if the dose received is not too high and if the dose is received over a long period of time.

Questions

1. In the 1950s, people accidentally contaminated by radioactive fallout from nuclear

   weapons testing developed beta burns and hair loss. The victims recovered from these effects within approximately six months. These radiation effects would be classified as

   a. early (acute) effects

   b. late (chronic) effects

2. The latent period for acute effects is than that for chronic effects.

   a. shorter

   b. longer

Factors Affecting Radiation Damage

- Amount of exposure
- Duration of exposure. This significantly affects the biological result since the body can repair most of the damage (even throughout the duration of exposure).
- Type of radiation.

- Biological variability factors. Exposed person's age, gender, general health, rate of metabolism, size, etc.
- Portion of the body exposed. The extent (volume) of tissue irradiated will influence the response.
  Most risk estimates are based on whole body exposures or doses. Different tissues have varying sensitivities to radiation.

Questions

3. Of the five factors that influence radiation damage, the one that takes into account the varying sensitivities of different organs or tissues to radiation is:

   a. the general health of the individual

   b. the portion of the body receiving the dose

4. If you were conducting an assessment of the potential for radiation-induced biological effects of a radiation accident, which of the following could be determined with radiation detection instruments?

   a. biological variability factors

   b. type of radiation

5. If you were exposed to a beta-gamma source such as iodine-131 (I-131), which term would be used to describe the radiation energy absorbed by your body?

   a. roentgen

   b. rad

6. You have responded to an accident involving a truck containing radionuclides destined for a research facility. The Incident Commander tells you that a package found on the ground indicates that it contains 0.2 Ci of iodine-131 (I-131). I-131 is a beta emitter, with a radioactive half-life of 8 days. What potential biological effects are associated with radiation exposure to this type of material, and what factors determine the extent of potential biological damage by this material?

Induced Radiation

Many atoms can be converted into radioactive isotopes from a nuclear detonation. A non-radioactive atom can absorb **neutrons** and become a radioactive isotope having one additional mass unit. The new atom can emit radiation as alpha, beta, x-ray, or gamma rays. Building materials, water and soil can be activated and become radioactive. Most atoms created by neutron activation have short half-lives and decay rapidly.

Fallout

About 10 percent of the total energy from a nuclear blast occurs in fallout, i.e., fine particles of radioactive dust that settle back to earth over a period of minutes to years. This radiation is largely due to the radioactivity of the fission products present in weapon debris, plus irradiated soil and moisture from the explosion.
Radioactive materials blasted high into the atmosphere by the force of a nuclear explosion can travel hundreds of miles before falling to earth, depositing radioactive contamination across thousands of square miles. The intensity and duration of contamination from fallout vary with the yield of the nuclear weapon and how close to the ground it had exploded.

Nuclear Winter

A scenario was suggested in the 1980s that a "nuclear winter" is a possible occurrence from nuclear detonations. This effect is caused by the absorption of sunlight when large amounts of soot are injected into the atmosphere. Sources of soot would include:

- Burning timber/forests
- Oil and petrochemicals (common target)
- Plastics, polymers, rubber, other man-made substances

Similar events have been observed when large volcanic eruptions have injected large amounts of dust into the atmosphere. The Mt. Tambora eruption of 1815 was followed by "the year without summer" in 1816, the coldest year in the last few centuries. Soot is more efficient in absorbing light than volcanic dust, and soot particles are small and hydrophobic and thus tend not to settle or wash out (from rain) as easily. More sophisticated recent research has confirmed the details of a nuclear winter. These studies predict that the amount of soot that would be produced by burning most of the major cities in the US and USSR would severely disrupt climate on a world-wide basis. The major effect would be a rapid and drastic reduction in global temperature, especially over land. Recent studies: Large-scale nuclear attack against urban or petrochemical targets → average temperature reductions of at least 10^{o}C would occur and last many months. This level of cooling far exceeds any that has been observed in recorded history, and is comparable to that of a full scale ice age. In areas downwind from attack sites, the cooling can reach 35^{o}C. It is probable that no large scale temperature excursion of this size has occurred in 65 million years. Smaller attacks would create reduced effects. However, most of the world's food crops are subtropical plants that experience dramatic declines in productivity if an average temperature drop of even <u>one</u> degree were to occur for even a short time during the growing season. The world maintains a stored food supply equal to only a few months of consumption. Thus, a war during the Northern Hemisphere spring or summer could still cause deadly starvation around the globe from this effect alone.

Day 4 of 4
Effect of a Nuclear Detonation in a U.S. City: Web-based Models
Activity

Directions: Please read and follow the directions. You will work at the computer in pairs.

Nuclear weapons are the most powerful of all WMDs. The detonation of a nuclear device by a terrorist group would result in catastrophic physical effects including blast overpressure, thermal effects and radiation contamination, and also cause tremendous psychological impacts worldwide.

During the Cold War between the United States and the Soviet Union (late 1940s to early 1990s), the nations of the world lived with the constant threat of nuclear war. With the end of the Cold War came the hope that the nuclear arsenals stockpiled by these and other countries would eventually be dismantled. Unfortunately, however, international terrorist organizations have recently made efforts to gain access to WMDs, including nuclear weapons, by attempting to recruit nuclear weapon scientists. In addition, certain nuclear nations may still pose a military threat to others.

In this activity we will use two mathematical models to assess two primary effects of a nuclear detonation in a major U.S. city: (1) initial blast damage; and (2) radioactive fallout.

Blast Effects

This first model will give an idea of the effects of ground-level and low-altitude nuclear weapon detonations. The model applies to conventional nuclear weapons as well as potential terrorist attacks.

High-definition aerial maps of selected U.S. cities are provided. The size of the bomb can be chosen by selecting the weapon's yield, as measured in kilotons (KT) or megatons (MT) of TNT equivalent. There is also the option of having the bomb delivered using an automobile at ground level or using an aircraft flying at an altitude that produces the widest area of destruction.

Refer to the website:

http://www.fas.org/programs/ssp/nukes/nuclearcalculators/nuclearwpneffctcalc.html

Using the website answer these questions.

1. Select **Chicago** and place Ground Zero directly over downtown (click and drag the colored rings). Select **Automobile** as the delivery method. Note the yield for a **1-KT** blast and refer to the color-coding of the rings.

   Red Circle: Intense heat from the explosion will likely cause widespread fires within this region.

   Blue Circle: Most homes are completely destroyed and stronger commercial buildings will be severely damaged due to the high pressure blast wave in this region.

Yellow Circle: Moderate damage to buildings causing some risk to people due to flying debris is caused by the blast wave in this region.

Does the damage from a 1-KT blast extend significantly beyond downtown?

2. Now change the weapon yield to 1 MT. Does the damage extend significantly beyond downtown?

3. Change the delivery method to **Aircraft**. Is there a difference in damage by the detonation? Explain your answer.

4. Would the populations of this city be protected from nuclear radiation by the presence of the structures?

5. What are the most common ailments associated with radiation exposure?

6. What is the yield of the largest nuclear detonation? What country was responsible for this detonation? Did it occur during wartime?

B. Fallout Calculator

A nuclear bomb has the potential to have an impact over a large area due to several factors such as wind and the size of the weapon. This model provides the distribution of fallout, by wind, from nuclear detonations of various yields. The contours depict calculated radiation doses of 300, 25, and 1 REM at 96 hours after detonation.

You may select wind speed (15, 30, or 45 miles per hour) and wind direction. You may choose from an assortment of yields ranging from 1 kiloton to 50 megatons.

Use http://www.fas.org/programs/ssp/nukes/nuclear_weapon_effects/falloutcalc.html.

Using the above link, locate **Chicago** and choose the following settings:

Wind Speed: **15 mph**
Wind Direction: **SE**
Yield: **1 KT**

1. Using the following key determine the approximate amount of REMs that would affect downtown Chicago: _______ REM.

    Blue Ellipse: 300 REM. At this accumulated dosage, the risk of fatalities is approximately 50% and increases drastically closer to the blast site.

Green Ellipse: 25 REM. At this range, only emergency workers and parties fully aware of the associated risks will (on a voluntary basis) be allowed to enter this region for the purpose of saving lives.

Red Ellipse: 1 REM. At this accumulated dosage, evacuation and sheltering is recommended.

2. Would any fallout extend into Indiana? Is this amount significant from a public health perspective?

3. Now change the wind speed to **45 mph**. Does this affect the extent of the fallout plume into Indiana?

4. Return to a setting of **15 mph** and change yield of explosion to **1 MT**. Does the amount of fallout over 1 REM change significantly?

5. Change the yield to **50 MT**. How does the range of fallout change? What happens with a wind speed of **45 mph**?

Name ________________________

Nuclear Weapons and Radiation Principles
Examination

Multiple Choice

1. Ionizing radiation includes all of the following EXCEPT:
   a. radio waves b. neutrons c. beta particles
   d. alpha particles e. gamma waves

2. Alpha radiation is identified as:
   a. particles the size of electrons, positive charge, low energy
   b. waves of electromagnetic energy
   c. two protons plus two neutrons; positive charge
   d. one pi meson and one neutrino
   e. none of the above

3. Beta radiation is identified as:
   a. particles about the size of electrons, relatively low energy
   b. waves of electromagnetic energy
   c. two protons plus two neutrons; essentially a helium nucleus
   d. one pi meson and one muon
   e. all of the above

4. Neutron radiation:
   a. Is a whole body hazard
   b. Is a skin irritant
   c. causes blindness
   d. does nothing to the body except heats the outer skin

5. Gamma radiation can be extremely destructive to living tissue because:
   a. has a very heavy mass
   b. the electric charge will shock you
   c. causes beta burns
   d. gamma radiation is <u>not</u> destructive to tissue
   e. none of the above

6. Interaction of alpha, beta, gamma rays with matter result in:
   a. half-life
   b. ionization of biological tissue
   c. thermoluminescence
   d. x-ray production
   e. pseudophosphorescence

7. Significance of ionization to humans:
   a. can result in fission reactions
   b. may disrupt DNA
   c. linked with cancer and genetic mutations
   d. causes severe beta burns
   e. b and c only

8. Which of the following is the radiation type capable of traveling the farthest in air?
   a. alpha
   b. beta
   c. delta
   d. gamma
   e. ions

9. Term for atoms which may have the same number of protons but different numbers of neutrons.
   a. fissile
   b. isotopes
   c. ionization
   d. cations
   e. atomic number

10. A natural source of background radiation:
   a. cosmic radiation from deep space
   b. internal (from the human body itself)
   c. radon gas from soil
   d. building materials (stone)
   e. all of the above

11. Nuclear weapons are designed and constructed based on:
   a. U-238 b. U-233 c. U-235 d. Pu-239 e. c and d only

12. Half-life may be defined as:
   a. The time required for half the atoms of a sample to decay to non-radioactive forms
   b. The amount of a victim's lifespan shortened following exposure to radiation
   c. A popular video game that was discussed during class
   d. The amount of time allowed before a responder can handle radioactive material

13. If an isotope has a half-life of 1 minute, how long will it take for 100 curies of that material to decay to 25 curies?
   a. one minute b. two minutes c. four minutes d. 144 minutes

14. A RDD (radiological dispersal device) is ____________?
   a. a rifle carried by soldiers
   b. a 'dirty bomb' (e.g., explosive attached to a small quantity of radioactive material)
   c. thermonuclear device with yields measuring in Mt
   d. sophisticated system to remove radiation from structures and equipment
   e. none of the above

15. A nuclear configuration which allows for the number of neutrons to increase in succeeding generations.

   a. HEU b. LD_{50} c. supercritical mass d. fissile e. Teller Effect

16. Hazard(s) from a thermonuclear explosion:
   a. electromagnetic pulse b. thermal (heat) c,. shock wave
   d. radiation e. all of above

17. The relative distribution of the effects in the previous question depends on:
    a. yield of the weapon
    b. location of the detonation
    c. characteristics of the local environment
    d. all of the above

18. The term ___ refers to the increase in atmospheric pressure as the result of a detonation.
    a. yield   b. mach stem   c. overpressure
    d. boosted   e. thermonuclear

19. Delayed effects of a nuclear detonation that may continue for hours up to years.
    a. overpressure   b. electromagnetic pulse   c. fallout
    d. deuterium and tritium   e. prompt radiation

21. The ___ occurs because of attack on a molecule by ionizing radiation followed by the destruction of the molecule.
    a. Compton scatter mechanism   b. indirect action mechanism
    c. direct action mechanism   d. The Curly Howard Effect

True-False

22. Alpha radiation can be stopped by a layer of dead skin. It is therefore not an external hazard to humans.

23 The approximately 25 (and growing) number of elements that are 'man-made' are known as 'transuranic' because they are heavier than uranium.

24. Large quantities of U-238 exist in nature; however, U-238 does not readily undergo fission.

25. Gamma rays have no mass and no charge; they are electromagnetic energy.

26. An unstable atom will attempt to reach stability by ejecting alpha or beta particles and/or releasing energy in the form of gamma radiation. This process is known as radioactive decay, or "radioactivity."

27. The process of removing an electron, leaving charged particles (the atom with a net positive charge), is "radioimmunosorption".

28. Beta burns may develop hours after the start of the exposure.

29. The key players in the Cold War were the Soviet Union (USSR) and Germany.

30. The yield of an explosive is typically expressed in terms of the quantity of TNT.

31. Implosion-type weapons require less fissile material than gun-type weapons.

32. An electromagnetic pulse from a nuclear detonation can erase computer memories and stop the functioning of electronic devices.

33. Time, distance and shielding are essential components of protection from nuclear radiation.

34. The largest nuclear weapon ever detonated was constructed by the Soviet Union (USSR).

35. The human body is constantly being exposed to small amounts of radiation from natural sources.

36. If a human is exposed to 1 REM of radiation, even if over many years, their risk of cancer is increased by 50% or more.